Evaluating the Practical Application of Underwater Explosion for Recycling

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Abstract

The explosion in water, a new crushing technique, is suitable in crushing and liberating hard materials such as the electric parts and waste construction materials. In this study, in order to evaluate the economical effectiveness of this method recycle system of composite materials of ceramics and metal recycle system as well as cellular phones recycling one were examined. Explosion of composite materials could reduce the landfilling area required for solid waste of insulator since well-separated ceramics could be reused, in contrary of ceramics-cement mix which couldn’t be used and remain as landfill solid waste. In explosion experiments on cellular phone, plastic-metal surface could be separated based on density difference between two materials. The cash-flow balances of these recycling processes were calculated. To minimize the process cost, it was suggested that a more effective explosion method and a relatively bid explosion pond are needed for the explosion. The payment balance of this system showed that the establishment of an efficient collection system, reduction in the transportation cost, was important. Investigation on the optimum cell phone recycling location based on shipping cost calculation found that Kanto, Tokai, Kinki and Kyusyu area are the optimum.

Key words: Explosion in water, Economical effectiveness, Composite materials, Cellular phones

1. Introduction

Nowadays, the demand of valuable metal is increasing rapidly but storage of natural resources has decreased year by year. Therefore, it is necessary to recycle valuable materials from some waste materials and to increase the recycling rate in order to eliminate the illegal dumping. However, some wastes are difficult to recover and recycle, because they are not fully liberated by using one of the conventional crushing or milling techniques. The explosion in water is a new crushing technique; it is suitable in crushing and liberating hard materials such as waste construction materials and the electric parts. The materials to be crushed are immersed in water and then the explosion in water was carried out by means of a small amount of explosive. The underwater shock waves in combination of the generated bubble pulses are very effective in liberating the materials of different densities. The idea was to use this technique as a pretreatment stage prior to recycling. The metals crushed or liberated by using this technique were leached much faster when compared with conventional crushing one2. This crushing method can be applied for liberation of many kinds of electric and mechanical tools.

In this study, the economical effectiveness of this underwater explosion system was evaluated. Especially, we focused on two types recycling systems; one is composite materials of ceramics and metal system such as insulator, isolator part of high-voltage capacitor and ceramic part of high-power transmitter and the other is cellular phone system. Cash-flow balance of these systems was studied respectively. Underwater explosion can be employed to liberate ceramics from composite materials processing...
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materials. This, in turn, will enable recycling of such materials and therefore decrease the amount of landfill. On the other side, in explosion experiments on cellular phone it is expected that plastic-metal surface can be separated based on density difference between two materials. Furthermore, the optimum recycling location based on shipping cost calculation was also investigated in these systems.

2. Principles of underwater explosion

During the explosion, the gas bubble is generated in water as shown in Fig. 1. When the explosion happens, the pressure of underwater shock wave suddenly reaches to be a peak and drops exponentially. The difference between the speeds of explosion shock wave in plastics, gum, glass and metals can enable the liberation of those materials at the boundary. The pressure can be controlled by the position and materials to be crushed. Waste materials are crushed and liberated using shock waves and bubble pulses generated by explosion in water.

Fig. 2 shows the experimental set-up. The materials to be crushed are immersed in water and then the explosion in water was carried out by means of a small amount of explosive (Fig. 2 (a)). The explosive is set in water near the surface of water pool. The underwater shock waves in combination of the generated bubble pulses are very effective in liberating the materials of different densities. Fig. 2 (b) shows an example of cellular phones which were exploded in water.

3. Economical evaluation of a recycling system using underwater explosion

In this study we focused on two types recycling systems:

A) Composite materials of ceramics and metal system such as insulator, isolator part of high-voltage capacitor and ceramic part of high-power transmitter.

B) Cellular phone system

Fig. 3 shows advantage of recycling system using underwater explosion in these system. As shown in Fig. 3 (a), it was a problem that the ceramic and the cement cannot be separated accurately though the ceramic and iron had been separated accurately. If this ceramics-cement mix was separated from at the boundary with a different density by this explosion method, ceramics can be reused at high price and it can reduce the landfilling area required for solid waste. On the other hand, in the conventional recycling method of cellular phone various precious metals have been recovered and recycled but the plastic materials were incinerated. If the plastic-metal surface can be separated from difference in density of two materials without the pretreatment by hand separation, and a lot of separated plastic could be reused as shown in Fig. 3 (b).
4. Economic assessment of two recycling systems

In this simulation I) Cash-flow balance of the system and II) Optimum recycling locations were calculated respectively. As to Cash-flow balance, <Income>, <Expense> and <Profit> were calculated as shown in Table 1. Calculation conditions are shown in Table 2, 3 and main calculation formulas of these systems are as follows.

*<Income>*

“Income” consists of “Recycle commission” and “Sales income of recycling material”. Sales income of recycling metal in cellular phone system consist of Fe, Au, Ag, Cu and Pd.

1) Recycle commission  
\[ \text{Recycle commission C} = (\text{recycle commission of composite material}) \]  \quad (1)  

\[ \text{Recycle commission P} = (\text{recycle commission of cellular phone}) \]  \quad (2)  

2) Sales income of recycling material  

\[ \text{Sales income of metal} = (\text{ratio of metal}) \times (\text{selling price in metal}) \]  \quad (3)  

\[ \text{Sales income of ceramics} = (\text{ratio of ceramics}) \times (\text{selling price in ceramics}) \]  \quad (4)  

\[ \text{Ratio of ceramics} = (0.5 - (\text{ratio of ceramics-cement mix})) \]  \quad (5)  

\[ \text{Total amount} = 1,000 \text{ [t/year]} \]  

\[ \text{Recycle commission} = 5,000 \text{ [yen/t]} \]  

\[ \text{Disposal cost for landfill} = 7,000 \text{ [yen/t]} \]  

\[ \text{Ratio of disposal material} = 20 \% \]  

\[ \text{Ratio of metal} = 30 \% \]  

\[ \text{Ratio of ceramics} = 50 - 0 \% \]  

\[ \text{Ratio of ceramics-cement mix} = 0 - 50 \% \]  

\[ \text{Selling price in metal} = 5,000 \text{ [yen/t]} \]  

\[ \text{Selling price in ceramics} = 10,000 \text{ [yen/t]} \]  

Sales income of metal = (ratio of metal) \times (selling price in metal) \quad (3)  

Sales income of ceramics = (ratio of ceramics) \times (selling price in ceramics) \quad (4)  

Ratio of ceramics = (0.5 - (ratio of ceramics-cement mix)) \quad (5)  

1) Recycle commission  

\[ \text{Recycle commission C} = (\text{recycle commission of composite material}) \]  \quad (1)  

\[ \text{Recycle commission P} = (\text{recycle commission of cellular phone}) \]  \quad (2)  

Sales income of plastic = (ratio of plastic) \times (selling price in plastic) \quad (7)
*<Expense>*

“Expense” consists of “Shipping cost”, “Processing cost” and “Disposal cost”.

3) Shipping cost

Shipping cost is obtained by multiplying the sum of drivers cost, highway cost, fuel cost with the required number of trucks and then dividing the resulting value by the throughput per day. In this case, as the density of cellular phone is lower than that of composed materials like insulator, the number of tracks needed to transport the discarded waste cellular phones is bigger than that of composed materials.

\[
\text{Shipping cost} [\text{yen/t}] = \frac{(\text{drivers cost} + \text{highway tolls} + \text{fuel cost}) \times \text{(the necessary number of truck)}}{\text{throughput per day}} \tag{8}
\]

\[
\text{Highway tolls} [\text{yen/day}] = (24.6 \times 1.05) \times \left(\frac{\text{Mean distance travelled for truck}}{\text{fuel efficiency in truck nt}}\right) \tag{9}
\]

\[
\text{Fuel cost} [\text{yen/day}] = \left(\frac{\text{Mean distance travelled for truck}}{\text{fuel efficiency in truck nt}}\right) \times \text{(retail gasoline price in truck)} \tag{10}
\]

\[
\text{The necessary number of truck} = \frac{\text{(total volume of recycle material)}}{\text{(one truck volume)}} \tag{11}
\]

4) Processing cost:

“Processing cost” is the sum of “Explosive cost” and “Labor cost”.

- Explosive cost

Explosion cost is obtained by dividing the product of explosive cost per 1 kg, the weight of explosive in one unit and the number of tank by throughput in this recycling system. The weight of explosive in one process can be described by the function of tank volume and amount of detonator or explosive.

\[
\text{Explosion cost} [\text{yen/t}] = \frac{(\text{explosive cost per 1 g}) \times (\text{the weight of explosive in one process}) \times (\text{the necessary number of tank})}{\text{throughput per day}} \tag{12}
\]

- Labor cost

Labor cost is obtained by dividing the product of the number of workers per one tank job, working cost per day and the number of tank by throughput in this recycling system. The number of required tank depends on amount of waste that can be processed in one tank, it is can be described by the function of tank volume and material density.

\[
\text{Labor cost} [\text{yen/t}] = \frac{(\text{the number of workers per one process}) \times (\text{working cost per day}) \times (\text{the necessary number of total tank})}{\text{throughput per day}} \tag{13}
\]

5) Disposal Cost

Disposal cost is obtained by dividing the product of disposal cost per material 1 ton and the weight of disposal materials by throughput in this recycling system. The weight of disposal materials can be described by the sum of landfill materials and ceramics-cement mix in composite material system or by the sum of landfill materials in cellular phone system.

\[
\text{Disposal cost} [\text{t/day}] = \left(\frac{\text{disposal cost per material 1 ton}}{\text{throughput per day}}\right) \times (\text{the weight of disposal materials}) \tag{14}
\]

\[
\text{The weight of disposal materials} [\text{t/day}] = \left(\frac{\text{ratio of disposal} + \text{ratio of ceramics-cement mix}}{\text{throughput per day}}\right) \tag{15}
\]

\[
\text{The weight of disposal materials} [\text{t/day}] = \text{(ratio of disposal)} \times \text{(throughput per day)} \tag{16}
\]

On the other hand, optimum recycling location was determined by the equation (17). This function shows the total sum of the product of W and D. Where W is the number of cell phone in each area, which is estimated from the total number and the population and D is distance between each area and the facility.

\[
\text{Evaluation function} = \sum (W_{\text{area}} \times D_{\text{area}}) \tag{17}
\]

5. Results and Discussion

5-1 Cash-flow balance

A) Composite materials of ceramics and metal system

Fig. 4 shows the cash-flow balance of this system at ceramic ratio = 0.3. (We call it “base case
In this base case, underwater explosion was still difficult to get bigger profit because of high explosive cost or high ceramics-cement mixed disposal ratio (0.2). However, if a ceramic separation ratio improves more, the profit can be expected to increase because the selling price of ceramics is relatively high.

Fig. 5 shows the change in cash flow balance of this system at various ceramic ratio. As can be seen from Fig. 4, sale income of ceramics became high with an increase in ceramic separation ratio and it is possible to get the profit slightly.

B) Cellular phone system

Fig. 6 shows the profit ratio calculated from main component ratio and selling price. It was found that even if Au and Pd compositions is included only a little, they particularly contribute to the profit due to their relatively high selling prices, nevertheless, the profit from plastic is not so high though the plastic content in the cellular phone is high.

Fig. 7 shows a cash flow balance at tank volume ratio = 1. (We call it “base case B”.) As can be seen, even if a plastic had all been separated and recycled, it would be difficult to get the profit because of the low selling price of plastic. In addition, the shipping cost rose slightly. It is thought that an increase in the number of the track and manpower cost raised transportation rates, because it is necessary to access many collection
points in order to collect the discarded cellular phones (Fig. 8). To get bigger profit, we have to try the more efficient explosive method or cheap shipping cost.

Fig. 9 shows change in cash-flow balance at various tank volume ratios. An increase of the explosion tank volume can be expected to decrease the necessary number of the expensive detonator and workers of this system (Fig. 10). As can be seen in this figure, it became possible to decrease the explosion cost by an increase in the explosion tank volume. However, to get the profit of the system, a little increase of the recycle commission and a decreasing labor cost for shipping were still needed, therefore, it was thought that discussion of a better collecting system in cellular phone was more necessary.

5-2 Optimal facility location

Finally, the optimal facility location based on shipping cost calculation was investigated. In calculation, four location points in the country which shows the minimum value of the sum of W·D, that is, the total amount of product waste materials and distance from recycle location (∑W·D), are selected.

Table 4, 5 show the calculation results of composite material system and cellular phone system. Regarding of composite materials recycling system it has been understood that Kanto, Kinki and Kyuoku are selected as the optimum recycling location points. On the other hand in terms of cellular phone recycling system the optimum recycling location points were Kanto, Tokai, Kinki and Kyusyu by the same analysis.

6. Conclusion

The effectiveness of the recycling system using underwater explosion, composite materials of ceramics and metal recycle system and cellular phones recycling were examined. In this simulation, cash-flow balance of these systems and optimum recycling location were calculated. In composite materials of ceramics and metal system, the profit of the system could be expected to increase with an increase of a ceramic separation ratio because of the high selling price of ceramics. In cellular phone system, an increase of the explosion tank volume could be expected to bring an in-
crease in this system profit by reducing the explosive cost and the labor cost. Investigation on the optimum recycling location found that Tohoku, Kanto, Kinki, Tyugoku area of system A and Kanto, Tokai, Kinki, Kyusyu area in system B, are selected as the optimum locations respectively.

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Table 4 The total amount of waste materials*distance from recycle location ((a) composite materials of ceramics and metal system)

<table>
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<th>area</th>
<th>the total amount of waste [t/yaer]</th>
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Evaluation 12264 4982 4071 5569 5693 6657 8509 12861 21691

Table 5 The total amount of waste materials*distance from recycle location ((b) cellular phone system)

<table>
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References